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A service restoration method for active distribution Network

Hong Xiaoyu, Xia Mingchao*, Han Yinghui*Beijing Jiaotong University, Beijing 100044, China*

Abstract:

For a large scale of distributed generations being connected to the power distribution network, the traditional service restoration methods cannot meet the demand of the distributed generation's large access which facing significant challenges. Service restoration of active distribution network (ADN) is a multi-objective, multiple-constraint, and complex optimization problem. Considering the user priority level, the load amounts restored, the counts of switch operation, the network loss after the power restoration, and the operation of power sources, this article establishes a restoration model based on grid actual situation, which is more realistic for the ADN. As a different dimension of different objective, this article proposes the generalized model in order to compare those solutions conveniently, the paper uses genetic algorithm to get recovery scheme. Results of case study show that the proposed model is effective.

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Key Words: Active Distribution Systems, Distributed Energy Resources, Service Restoration, Genetic Algorithm Introduction;

1. Introduction

The service restoration of the traditional distribution network is by changing the status of the section switches and loop switches to meet operational requirements: distribution network remain in open-loop status, restore as much as possible non-fault outage area, and adopt the optimal power recovery scheme. The resulting solution is a series of switch action combination[1]. The running topology structure of distribution network is not radial after the distributed generations connected to grid. Meanwhile, as the operation mode, the power flow, the short-circuit current, and the distribution characteristics change, the service restoration demands change[2][3], a more realistic mathematical model containing DGs needs to be further in-depth study.

When the distribution network with DGs breaks down, the traditional recovery strategy will remove all the distributed generations to greatly protect network security, but this will affect the reliability of power supply at the same time. ADN refers to distribution network having the ability of combination control various distributed energy resources (distributed generation, controllable load, energy storage, demand side management, etc.), and effectively connects generation with consumers needs through active control and active management [4]. By changing section switches and loop switches status under ADN service restoration, it can change the topological position of DGs in the distribution network, resulting in the change in the supply range of DGs. Without removing DGs, service restoration of ADN can improve operation reliability and quality of the distribution network[5]. There are many types of DGs, and their mathematical models undertake different tasks, which cannot be processed according to the power supply in a conventional power grid. So this article has carried on a preliminary discussion on this question: It is divided into black-start DG (BDG) and nonblack-start DG (NBDG) according to whether DG can be looked as a backup power system when a fault occurs[6]; Based on the position of

* Xia Mingchao. Tel.: +86 10 5168-5206; fax: +86 10 5168-7101.

E-mail address: mchxia@bjtu.edu.cn.

DGs in the network divide DGs into in the failure area inside and outside; Based on different types of DGs, different mathematic models of different service restorations will be established.

2. DG classification and models of service restoration

Different DGs have different operation modes and applications. It is divided into BDG and NBDG according to whether DG can be looked as a backup power system when a fault occurs. BDG can serve as a backup power supply and run parallel or islanded operation; While NBDG can operate parallel, but it can't run islanded operation [6]. BDG includes joint generating set, passive type inverter and separately excited generator set, fuel cell, electric vehicle, wind power and photovoltaic power generation with energy storage. NBDG includes self-excited generator set, wind power and photovoltaic power generation without energy storage [7]. In the islanded operation mode, energy storage device can act as the complement of short-term power gap and the main control unit to offer the voltage and frequency reference for other distributed power supplies. But due to the limitation of capacity, the islanded operation time generally will not be too long. Based on different types of DGs, and dividing DGs into inside the non-fault area and outside the non-fault area, different mathematic models of different service restorations will be established (choose different mathematical models according to the actual situation).

2.1 When DG can be used as BDG

- (1) When DG inside the non-fault power outage area
 - a. When there are pathways between the non-fault area and system, consider DG parallel operation first.
 - b. When there is no pathway between the non-fault area and system, consider DG islanding operation first (randomness of wind power and photovoltaic is big, so they cannot run islanded, wind power or photovoltaic equipped with energy storage can run islanded).
- (2) When DG outside the non-fault power outage area, it remains its initial state

2.2 When DG can be used as NBDG

- (1) When DG inside the non-fault power outage area
 - a. When there are pathways between the non-fault area and system, consider DG parallel operation first.
 - b. When there is no pathway between the non-fault area and system, disconnect its export circuit breaker, neither operate parallel nor run island.
- (2) When DG outside the non-fault power outage area; it remains its initial state.

3. Mathematical model of service restoration

The goal of the service restoration of Active Distribution Network with DG is: meeting the connectivity and radial topology demand, feeders, load transformers and switches are not overload after service restoration, to achieve minimum switch operation, shortest power outage time, minimum network loss, most loads restored, stable and reliable, load balance, maxim feeder capacity margin [8][9][10].

Model of service restoration with DGs is established as follows:

3.1 Priority in load restoration

Different loads require different reliability of the power - loads are divided into two priority levels to recover maximum load of power supply, meanwhile make sure high priority loads restore first. The objective function is as follows:

$$\max f_1(x) = \sum_{i=1}^n A_i S_i P_i \quad (1)$$

$$\max f_2(x) = \sum_{i=1}^n A_i S_i Q_i \quad (2)$$

Where n is the total number of all branches to participate in the service restoration; x is the current state of the network, which is relevant with the closed state of all branches participated in the service restoration; S_i is the closed state of the switch number i where “0” means open and “1” means closed; A_i , P_i and Q_i are the weight coefficient of priority of the node load, the rated active power and the rated reactive power which is connected with the branch number i . In order to ensure the highest priority level load in the power supply, the weight coefficient of the highest priority level is greater than the weight coefficient of second priority level.

3.2 The minimum counts of switching operation

$$\min N = \sum_{i=1}^n |K_i - S_i| \Rightarrow \max f_3(x) = \frac{1}{N} \quad (3)$$

Where K_i is the initial closed state of the branch numbers i ; S_i is the closed state of the switch after restoration; N is the number of switch operation.

3.3 As far as possible to reduce the line loss after service restoration

Line loss directly affects the economic operation of the distribution network, in order to improve the economic benefit of the service restoration; we should reduce the line loss as much as possible.

$$\min \sum_{j=1}^{n_l} P_{sun(j)} \Rightarrow \max f_4(x) = \frac{1}{\sum_{j=1}^{n_l} P_{sun}(j)} \quad (4)$$

Where $P_{SUN(j)}$ is the active power loss of the branch number j ; n_l is a collection of all branch in the network.

3.4 Maximize the power supply of the distribution generation

$$\max f(x) = \frac{1}{\sum_{i \in C} (P_{Gmax}^i - P_G^i)} \quad (5)$$

Where P_{Gmax}^i expresses maximize the power supply of the generation i .

4. Constraint conditions

4.1 The constraints of node voltage

$$U_{imin} \leq U_i \leq U_{imax} \quad (6)$$

Where U_{imin} , U_{imax} respectively express the lower limit and upper limit of the voltage of the node i .

4.2 Constraints of line current

$$I_{jmin} \leq I_j \leq I_{jmax} \quad (7)$$

Where I_{jmin} , I_{jmax} express the lower limit and upper limit of current of the node i .

4.3 Output of the distribution generation meets the demands.

$$P_{Gmin}^i \leq P_G^i \leq P_{Gmax}^i \quad (8)$$

Where P_G^i , P_{Gmin}^i and P_{Gmax}^i express the actual output, the lower limit and upper limit of power supply output of the generation i . Photovoltaic (pv) power and wind power will use prediction data[11].

4.4 The electric vehicle available capacity constraints

Electric vehicles can be used as emergency power supply to the load, due to the uncertainty of traffic and the electric vehicles randomness of journey, the power that the electric vehicles supply is not sure too [12]. The power that electric vehicle can supply is $a \cdot P_{VEtotal}$ (a express power margin that electric vehicles can provide to the load, $P_{VEtotal}$ express the total power of the electric vehicles).

4 Calculate process based on Pareto genetic algorithm of optimal path control

Service restoration of active distribution network (ADN) is a multi-constraint, multi-objective, multi-period, multi-combination complex nonlinear optimization problem that containing discrete and continuous variables. Nowadays, to solve the problem mainly contain mathematical optimization, heuristic search, artificial intelligence algorithm. Mathematical methods are mature and able to get global optimum that independent on distribution network initial structure. However, with the distribution network structure becoming complex, the expansion of power outage regional, the computation time will greatly be extended, that complex large-scale systems cannot be handled with this method. Search results that bases on heuristic search is often associated with the network structure, the result of the algorithm is not stable, the number of feasible solution is huge, for large complex distribution network the calculation efficiency is low, and it cannot be guaranteed to find the global optimal solution. Artificial intelligence global optimization capability is strong, but greatly influenced by weight coefficient when dealing with multi-objective optimization problem [13]. In recent years, the pare to genetic algorithm of optimal path having favorable optimization ability, are widely used solving multi-objective optimization problem. This article uses the pare to genetic algorithm of optimal path to establish model and get solution. The algorithm process of service restoration of active distribution network as follows:

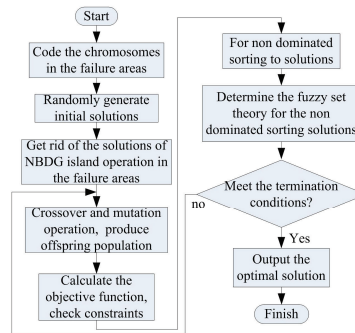


Figure 1. Simple flow chart of genetic algorithm

In practical applications, service restoration of ADN contain the only one scheme. Pareto optimal path algorithm gets a set of optimal solutions, so we need to select the optimal solution according to the actual situation. Normalized based on the fuzzy theory to determine the optimal solution, the fuzzy membership functions as follows:

$$Obj(l) = \begin{cases} 0.0 & f_l \leq f_l^{\min} \\ \frac{(f_l^{\max} - f_l)}{(f_l^{\max} - f_l^{\min})} & f_l^{\min} < f_l < f_l^{\max} \\ 1.0 & f_l \geq f_l^{\max} \end{cases} \quad (9)$$

$$Obj = \sum_{l=1}^{N_{obj}} Obj(l) \quad (10)$$

Where f_l express the objective function l , f_l^{\min} and f_l^{\max} respectively express the maximum value and the minimum value of the objective function l , N_{obj} express number of the objective function, the individual having maximum value as the optimal solution at last.

5 Case study

This article uses the IEEE standard 33 nodes(a common standard system) distribution network as an example. As shown in figure 2, dotted line 1-5 for loop switches, others for section switches. Section switches are all closed, contact switches are entirely open in the initial state, rated voltage is 12.66kV.

The distributed generations of grid-connected operation will be in the 10, 16, 24, 31, capacity respectively for 100kW, 70kW, 90kW, and 100kW as shown in table 1. Node 10 connect photovoltaic power generation, node 16 connect fuel cell, node 24 for traditional constant speed asynchronous wind turbines, node 31 for electric vehicles. When 5-6 branch breaks down, the fault node downstream area 6 to 17 will lose power. The rated capacity of loop branch 1, 2, 3, 4 is 500kW, 8, 12 are important loads. 10 and 24 nodes generations for NBDG in the 33 nodes system, but they can be used as BDG when they run parallel with 16 nodes. Node 16 and node 31 generation respectively as BDG, they can run in island. Based on the genetic algorithm to encode the switch, uses the parallel processing method to restore power under the condition of the constraints. Nodes 10 and 16 generations in the non-fault area, when node 10 generation exists pathways with the system, or operates in parallel with the 16 node generation, node 10 generations maintain connection; Others, node 10 generation disconnect. Node 24 and node 31 are out the non-fault area, maintaining grid-connected. Distribution network without DGs, results are shown in table 2. Distribution network with DGs is shown in figure 3, results are shown in table 2.

Table1. Installation position、 capacity and the type of DGs

DG number	installation node	rated capacity	capacity	DG type
1	10	200kW	100kW	NBDG
2	16	200kW	70 kW	BDG
3	24	200kW	90 kW	NBDG
4	31	200kW	100 kW	BDG

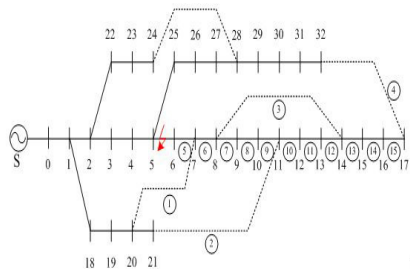


Figure 2. IEEE standard 33 nodes network

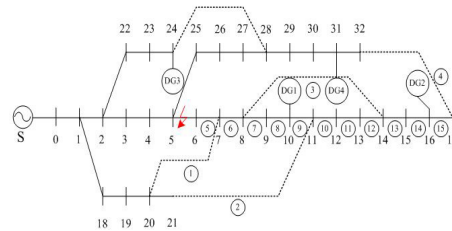


Figure 3. 33 nodes distribution network with DG

Table2. The results of service restoration of distribution network

operation DG	operation switch	operation number	restored load	losses
Non DG	1,2,4,9,15	5	restore all the load	147.3kW
All the DG	1,2,14	3	restore all the load	123.7kW

6 Conclusion

This article establishes a more practical mathematical model for service restoration of power distribution network containing DGs. Different kinds of DGs were divided into different purpose in restoration considering its type and topology position. Multi-objective functions and multiple-constraint functions were presented and genetic algorithm was adopted to get optimal result. Simulation results using IEEE 33 nodes show that this method can ensure the restoration of the important loads, reduce the loss of the network fault recovery, improve the economic benefit of the power grid operation; Moreover, it can shorten the restoration time, reduce the times of operating switch, and improve the utilization of clean energy.

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Biography

Hong Xiaoyu(1988-), postgraduate, the main research direction is service restoration of active distribution network.

Xia Mingchao (1976-), associate professor, the main research direction include substation automation, smart power distribution system, including control and protection of power distribution system, on-line monitor and diagnose of power devices.

Han Yinghui (1988-), postgraduate, the main research direction is micro-grid.